2.40 FORCE AND MOMENT GENERATION

To simulate the trajectory of a missile, the forces acting on it must be determined. Forces acting through the center of gravity (CG) of the missile will result in movement or translation. A force not acting directly on the CG creates a moment resulting in a rotation. A body coordinate system (Figure 2.40-1) is defined to provide a 3-dimensional reference frame in which these forces and moments can be evaluated. Translation is movement along an axis and rotation is about an axis.

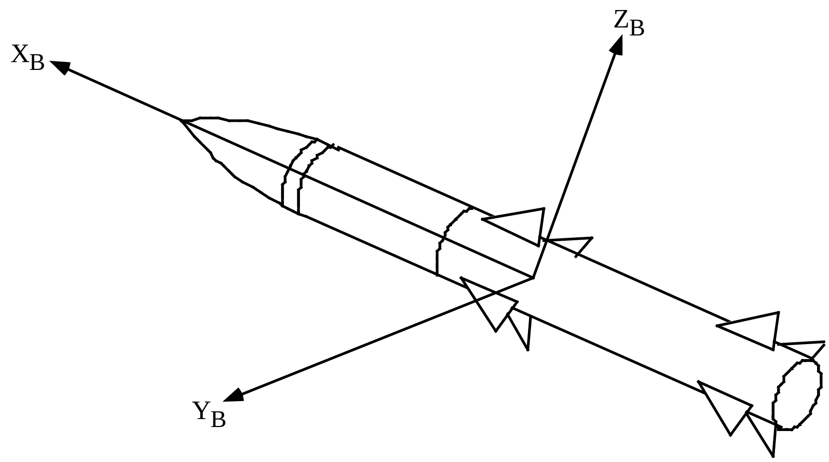

FIGURE 2.40-1. Body Coordinate System.

The forces which act on a missile in flight are thrust, drag, lift and missile weight. Thrust is generated by the rocket engine and its magnitude is dependent on the dimensions and operating characteristics of the specific rocket engine. The major component of thrust is directed along the positive x-axis, with some minor components in the y and z directions if the engine nozzle is movable.

The estimation of drag is a very complicated problem due to the numerous types and sources of drag. If sufficient configuration and wind tunnel data is available, however, values for drag can be determined. Drag is effected by vehicle shape, orientation, velocity, atmospheric conditions and control surface deflections. All components of drag are directed opposite to the velocity vector.

Lift is generated by the missile body and control surfaces. Lift is affected by vehicle shape, orientation, velocity and control surface deflections. The lift vector component is perpendicular to the velocity-drag components. Aerodynamically, lift acts through the center of pressure of the vehicle.

Missile weight is directed down in a body coordinate system (-z) or to the center of the earth in an inertial coordinate system.

Primary moment generation is due to the fact that the center of gravity is not collocated with the aerodynamic center of pressure. Thus lift creates a moment about the cg. Also, the control surfaces and the missile body itself generate asymmetric forces which result in moment generation. When resolved, the components of each of these forces will cause the missile to translate along or rotate about some combination of the 3 axes. Rotations about the x, y and z axes are called roll, pitch, and yaw, respectively.

By resolving the force and moment components and applying Euler's equations of motion an accurate representation of the missiles' position and orientation can be calculated in the body coordinate system.

In support of the calculation of aerodynamic forces, the determination of certain local atmospheric conditions is required to compute essential missile operating parameters. The atmospheric conditions being air density and local speed of sound and the missile operating parameters being Mach number and dynamic pressure. Using a standard atmospheric model, air density and local speed of sound are determined as a function of altitude. Missile total velocity in combination with the local speed of sound, enables the determination of the Mach number at which the missile is flying. Both missile velocity and air density are required for computing the magnitude of the wind force exerted on the missile body, a quantity known as dynamic pressure. All of these quantities are critical in the calculation of aerodynamic forces.

In order for a computer-simulated missile to interact with a computer-simulated target, both must be flying in the same inertial frame of reference. An additional transformation is required to determine the missile's position and orientation in this inertial frame of reference. Determining the missile's position in inertial space requires knowing what inertial coordinates the missile occupied while still at rest (latitude, longitude, altitude), then calculating its new position within that inertial frame from the body coordinate system using trigonometry. Determining the missile's orientation in inertial space is slightly more complicated. Again, knowing what the missile's orientation was while still at rest (azimuth, elevation), then keeping track of the changes in pitch, roll, and yaw calculated from the body coordinate system. The deltas in rotation are then converted into inertial directions using angle relations between the two coordinate systems defined by a direction cosine transformation matrix. The angles pitch, roll and yaw which define the missile orientation are known as the Euler angles and are commonly represented by the Greek letters; Theta (θ), Phi (φ), and Psi (ψ), respectively.

An additional complication between the two reference frames is that the direction the missile is flying is defined by the velocity vector which is not aligned with the missile body. Figure 2.40-2 shows this relationship. The angle between the missile body and the velocity vector is defined as the angle-of-attack (AOA), and the inertial direction and angle of the velocity vector are called the heading and flight path angle respectively. The values define the direction in which the missile is flying in inertial space, not the direction the nose is pointing.

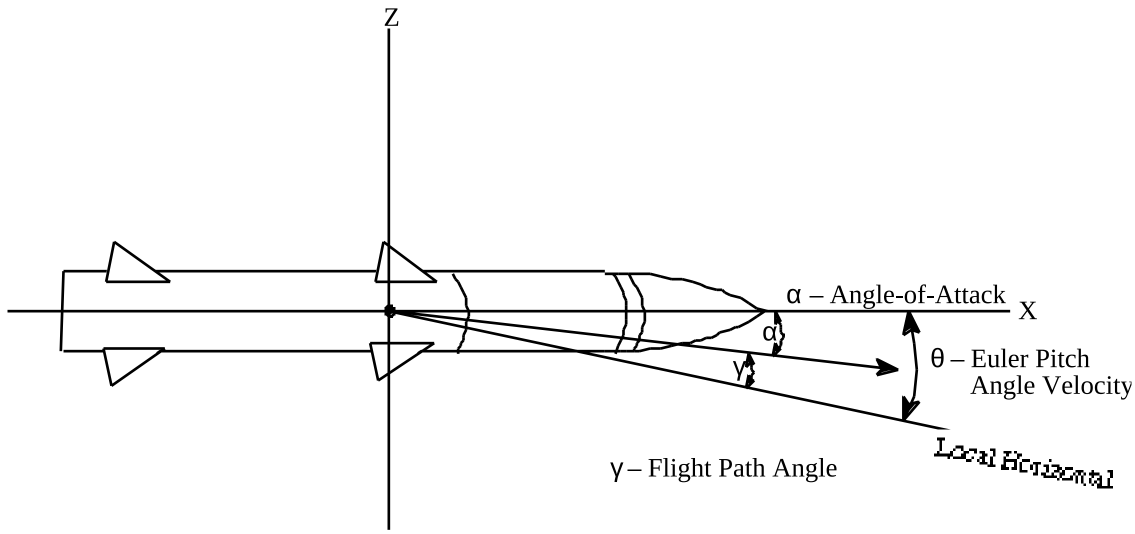

FIGURE 2.40-2. Velocity Vector.

2.40.1 Functional Element Design Requirements

This section contains the design requirements necessary to fully implement the force and moment generation simulation.

1. ESAMS will calculate the aerodynamic forces acting on the missile due to drag, and lift, and the resulting moments using local atmospheric conditions and missile operating parameters.
2. ESAMS will compute the angle relations required to transform body rotations into inertial orientation.
3. ESAMS will provide a capability for computing heading and flight path angles of the missile velocity vector and missile pointing (Euler) angles in inertial space.

2.40.2 Functional Element Design Approach

This section describes the design approach (equations and algorithms) implementing the design requirements of the previous section.

ESAMS uses a standardized body axis system centered on the center of gravity defined as follows:

X_B-axis, called the roll axis, longitudinally along the body of the missile positive forward.

Y_B-axis, called the pitch axis, laterally sideward, positive to the left if viewing the missile from the rear.

Z_B-axis, called the yaw axis, laterally upward, positive up to form a right handed system with the other two.

A three-dimensional system has 6 degrees of freedom, 3 translational and 3 angular. Table 2.40-1 defines the forces and moments acting on the missile, the linear and angular velocities, and the moments of inertia. All but products of inertia are shown in Figure 2.40-3.

TABLE 2.40-1. Force and Moment Symbol Definitions.

	Roll Axis X_B	**Pitch Axis Y_B**	**Yaw Axis Z_B**
Angular rates	p	q	r
Component of missile velocity along each axis	V_x	V_y	V_z
Components of force acting on missile along each axis	F_x	F_y	F_z
Moments acting on missile about each axis	L	M	N
Moments of inertia about each axis	A	B	C
Products of inertia	D	E	F

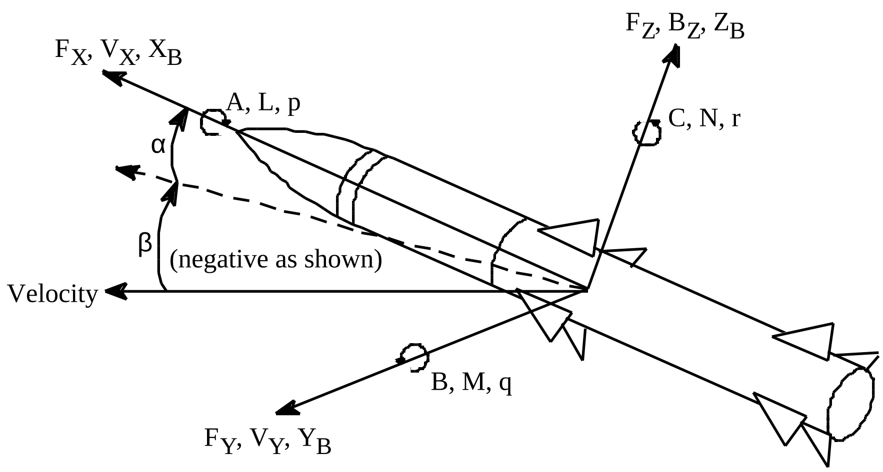

FIGURE 2.40-3. Force and Moment Conventions.

The yaw plane is the xy plane and the pitch plane is the xz plane. The following angles are defined:

α = incidence in the pitch plane
β = incidence in the yaw plane

There are six equations of motion for a body with six degrees of freedom, three force equations (of the form F = Ma) and three moment equations. These equations are known as Euler's equations of motion. Using symbols from Table 2.40-1, Euler's equations are as follows (Reference 24, page 48):

$$m\left(\dot{V}_x + qV_z - rV_y\right) = F_x \quad [2.40\text{-}1]$$

$$m\left(\dot{V}_y + rV_x - pV_z\right) = F_y \quad [2.40\text{-}2]$$

$$m\left(\dot{V}_z - qV_x + pV_y\right) = F_z \quad [2.40\text{-}3]$$

$$A\dot{p} - (B - C)qr + D\left(r^2 - q^2\right) - E\left(pq + \dot{r}\right) + F\left(rp - \dot{q}\right) = L, \text{ roll} \quad [2.40\text{-}4]$$

$$B\dot{q} - (C - A)rp + E\left(p^2 - r^2\right) - F(qr + \dot{p}) + D(p\,q - \dot{r}) = M\text{, pitch} \qquad [2.40\text{-}5]$$

$$C\dot{r} - (A - B)pq + F\left(q^2 - p^2\right) - D(rp + \dot{q}) + E(qr - \dot{p}) = N\text{, yaw} \qquad [2.40\text{-}6]$$

where m = missile mass

ESAMS simplifies the force equations to:

$$m\left(\dot{V}_x + qV_z - rV_y\right) = F_x \qquad [2.40\text{-}7]$$

$$m\left(\dot{V}_y + rV_x\right) = F_y \qquad [2.40\text{-}8]$$

$$m\left(\dot{V}_z - qV_x\right) = F_z \qquad [2.40\text{-}9]$$

The terms pV_z from Equation [2.40-2] and pV_y from Equation [2.40-3] can be neglected if roll rate p is kept small and assuming V_z and V_y are small compared to V_x.

The moment equations may be simplified by assuming the missile has 2 axes of symmetry. If the moment of inertia in pitch is the same as moment of inertia about yaw, the products of inertia, D, E and F, become zero. The moment equations are now (Reference 24, page 48):

$$A\dot{p} - (B - C)qr = L \qquad [2.40\text{-}10]$$

$$B\dot{q} - (C - A)rp = M \qquad [2.40\text{-}11]$$

$$C\dot{r} - (A - B)pq = N \qquad [2.40\text{-}12]$$

Again, if roll rate is kept small, the terms rp and pq can be neglected. A further simplification employed by ESAMS is to assume the missile is perfectly roll stabilized. These further reduce the moment equations to:

$$A\dot{p} = 0 \text{ (roll)} \qquad [2.40\text{-}13]$$

$$B\dot{q} = M \text{ (pitch)} \qquad [2.40\text{-}14]$$

$$C\dot{r} = N \text{ (yaw)} \qquad [2.40\text{-}15]$$

The only contribution to pitch rate, q, is a moment about the pitch axis, the only contribution to yaw rate, r, is a moment about the yaw axis and roll will be held to zero. The system has now been decoupled. These simplifications are reasonable, unless the missile is very asymmetrical.

Design Element 40-1: Determination of Missile Operating Parameters; Total Velocity, Mach Number and Dynamic Pressure

The computation of missile total velocity requires the vector addition of the three inertial components of velocity. Thus, total velocity (V_t) is calculated from the sum of the squares as follows:

$$V_t = \sqrt{\left(V_{I_x}^2 + V_{I_y}^2 + V_{I_z}^2\right)} \qquad [2.40\text{-}16]$$

where $V_{Ix,y,z}$ = Component Velocity in inertial X, Y, and Z directions

Local speed of sound is required to compute missile Mach number. Using a standard atmospheric model, the local speed of sound (Va) is determined as a function of altitude. In agreement with Reference 25, Mach number can now be computed as follows (Reference 25, page 25):

$$\text{Mach} = \frac{V_t}{V_a} \qquad [2.40\text{-}17]$$

Air density is required to compute dynamic pressure. Again, using a standard atmospheric model, the local air density, r, is determined as a function of altitude. Dynamic pressure, Q, can be computed as follows (Reference 25, page 36):

$$Q = \frac{1}{2}\rho V_t^2 \qquad [2.40\text{-}18]$$

Design Element 40-2: Calculation of Direction Cosine Transformation Matrix

The inertial coordinate system is based on the right hand rule with the following definitions. Positive x is directed east, positive y is north and positive z is up. To convert translations and rotations from inertial to body coordinates, relations between the two systems need to be determined. The development of the direction cosine transformation matrix follows.

The derivation of the direction cosine transformations is illustrated by an example. Three general rotations defined by the Euler angles will be made, and their effect on the resulting position will be determined. In Figure 2.40-4, the aircraft has been rotated through three angles with respect to the translated inertial coordinate system $\left(X_I',\ Y_I',\ Z_I'\right)$. It has been rotated through a yaw angle ψ, a pitch angle θ, and a roll angle φ.

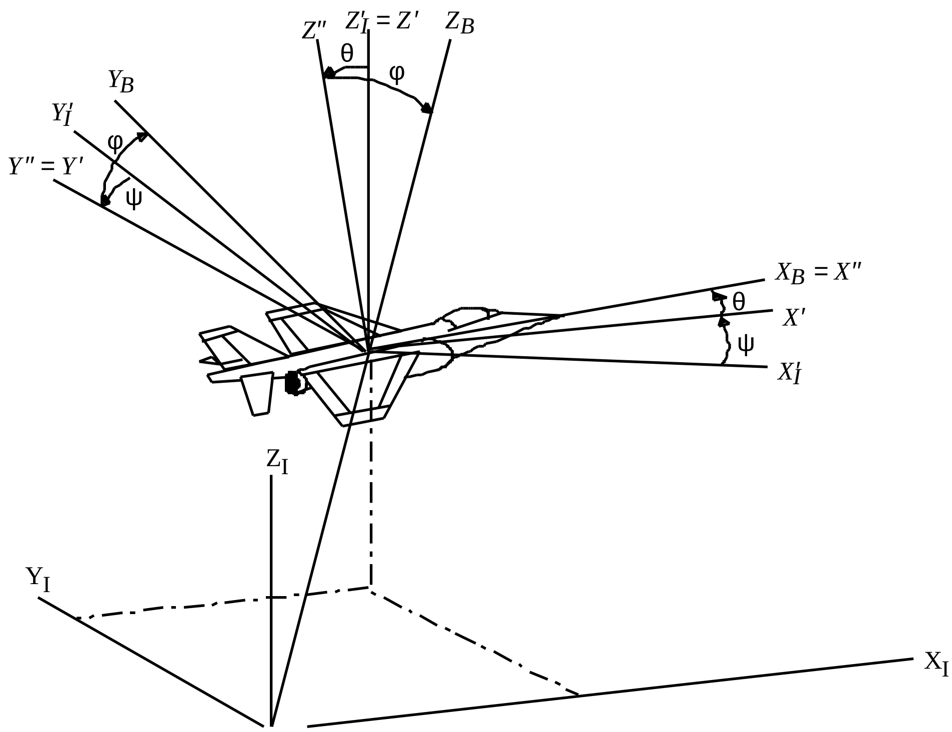

FIGURE 2.40-4. Rotation of an Aircraft with Respect to an Inertial Coordinate System.

The rotation in yaw is accomplished by rotating about the Z_I' axis shown in Figure 2.40-4. This rotation causes any point along the x-axis to be displaced to *cos*(ψ) in the inertial frame. Also, any point along the x-axis is displaced by *sin*(ψ) in the y direction. Similarly, points along the y-axis are displaced in x and y by –*sin*(ψ) and *cos*(ψ) respectively.

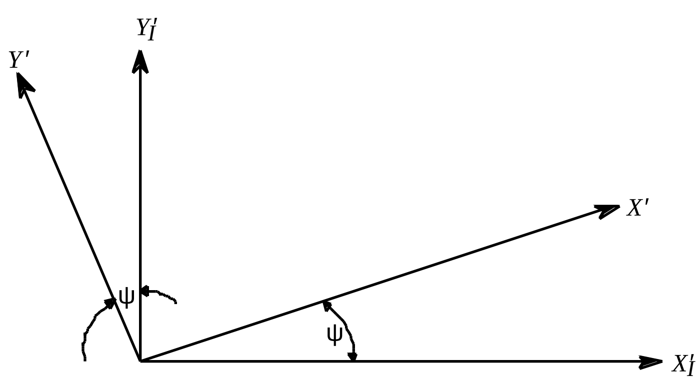

FIGURE 2.40-5. Rotation in Yaw.

If these relationships are defined using a matrix, the following is obtained for a rotation in yaw.

$$[\mathrm{YAW}] = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad [2.40\text{-}19]$$

By similar development matrices for pitch and roll are derived.

$$[\text{PITCH}] = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \qquad [2.40\text{-}20]$$

$$[ROLL] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{bmatrix} \qquad [2.40\text{-}21]$$

Thus, a point in inertial space can be located for a body coordinate system that has undergone yaw, pitch, and roll rotations by use of the following relation:

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = [\text{ROLL}][\text{PITCH}][\text{YAW}]\begin{bmatrix} X_I' \\ Y_I' \\ Z_I' \end{bmatrix} \qquad [2.40\text{-}22]$$

After matrix multiplication, the following result is obtained:

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & \sin\theta \\ -\sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi & -\sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi & \sin\varphi\cos\theta \\ -\cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi & -\cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi & \cos\varphi\cos\theta \end{bmatrix}\begin{bmatrix} X_I' \\ Y_I' \\ Z_I' \end{bmatrix} \qquad [2.40\text{-}23]$$

This matrix represents the Euler angle inertial to body transformation matrix for a general rotation in 3-axis. Because these terms will be referred to again, each will be assigned a single variable. They are detailed as follows:

$$\begin{aligned}
\rho_x &= \cos\theta\cos\psi \\
\rho_y &= \cos\theta\sin\psi \\
\rho_z &= \sin\theta \\
\pi_x &= -\sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi \\
\pi_y &= -\sin\varphi\sin\theta\sin\psi - \cos\varphi\cos\psi \\
\pi_z &= \sin\varphi\cos\theta \\
\eta_x &= -\cos\varphi\sin\theta\cos\psi - \sin\varphi\sin\psi \\
\eta_y &= -\cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi \\
\eta_z &= \cos\varphi\cos\theta
\end{aligned}$$

These are the equations used to generate the inertial to body transformation matrix from the primary Euler angles. Under certain situations based on missile orientation in inertial space (to be discussed in Missile Movement), an alternate transformation matrix using a secondary set of Euler angles is required. This secondary set of Euler angles is derived from rotations around a different set of intermediate axes. In matrix form, this transformation matrix from secondary Euler angles is:

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \begin{bmatrix} cos\,\psi\, cos\,\varphi - sin\,\psi\, cos\,\theta\, sin\,\varphi & sin\,\psi\, cos\,\varphi + cos\,\psi\, cos\,\theta\, sin\,\varphi & sin\,\theta\, sin\,\varphi \\ -cos\,\psi\, sin\,\varphi - sin\,\psi\, cos\,\theta\, cos\,\varphi & -sin\,\psi\, sin\,\varphi + cos\,\psi\, cos\,\theta\, cos\,\varphi & sin\,\theta\, cos\,\varphi \\ sin\,\psi\, sin\,\theta & -cos\,\psi\, sin\,\theta & cos\,\theta \end{bmatrix} \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} \qquad [2.40\text{-}24]$$

If the secondary Euler angles are being used, the above simplified variables become:

$$\begin{aligned}
\rho_x &= cos\psi cos\varphi - sin\psi cos\theta sin\varphi \\
\rho_y &= sin\psi cos\varphi + cos\psi cos\theta sin\varphi \\
\rho_z &= sin\theta \sin\varphi \\
\pi_x &= -cos\psi sin\varphi - sin\psi cos\theta cos\varphi \\
\pi_y &= -sin\psi sin\varphi - cos\psi cos\theta cos\varphi \\
\pi_z &= sin\theta cos\varphi \\
\eta_x &= sin\psi sin\theta \\
\eta_y &= -cos\psi sin\theta \\
\eta_z &= cos\theta
\end{aligned}$$

Design Element 40-3: Velocities With Respect to Air Mass

As shown in Figure 2.40-2, the velocity vector is not aligned with the body axis. The difference being defined as the angle of attack. An accurate determination of the AOA for the fin planes (control surfaces) requires the effect of wind speed and direction be accounted for. The first step in this process requires wind speed and direction defined in the inertial reference frame. In ESAMS this is accomplished using the WINDS subroutine. It provides wind speed and direction based on missile altitude.

Inertial Velocity With Respect to Wind

The wind vector generated in ESAMS has only x and y inertial components. A wind azimuth of 0 degrees is from the east blowing west. A wind of 90 degrees is from the north blowing south, and so on around the compass counter-clockwise. With these conventions defined, the following equations define the inertial velocity with respect to the wind:

$$V_{W_x} = V_{I_x} + V_W\, cos\,\tau$$

$$V_{W_y} = V_{I_y} + V_W\, sin\,\tau \qquad [2.40\text{-}25a,b,c]$$

$$V_{W_z} = V_{I_z}$$

where $V_{Wx,y,z}$ = Component Wind Velocity in inertial x, y, and z directions
$V_{Ix,y,z}$ = Component Velocity in inertial x, y, and z directions
V_W = wind speed
τ = wind azimuth (direction wind is from)

Body System Velocity With Respect to Wind

The defined relation between the body system with the inertial system and the single variable assigned to each term is the direction cosine matrix of Euler angles (Equation

[2.40-23 or 24]). Using this matrix and knowing inertial velocity components with respect to the wind, body system velocities with respect to the wind are determined as follows:

$$V_{B_x} = \rho_x V_{W_x} + \rho_y V_{W_y} + \rho_z V_{W_z}$$
$$V_{B_y} = \pi_x V_{W_x} + \pi_y V_{W_y} + \pi_z V_{W_z} \quad [2.40\text{-}26a,b,c]$$
$$V_{B_z} = \eta_x V_{W_x} + \eta_y V_{W_y} + \eta_z V_{W_z}$$

where $V_{Bx,y,z}$ = Component Body Velocity wrt Wind in X, Y, and Z directions
$V_{Wx,y,z}$ = Component Wind Velocity in inertial X, Y, and Z directions
V_W = wind speed
ρ, π, η = Term simplifications from transformation matrix

These velocity components, V_{Bx}, V_{By}, and V_{Bz}, define the velocity vector in relation to the body axis and they can be used directly to compute angles of attack.

Design Element 40-4: Pitch and Fin Plane AOA

The pitch AOA, α, is defined as the angle between the velocity vector and the missile body in the x-z plane. Figure 2.40-2 shows a positive a and a negative V_{Bz}.

Therefore: Pitch AOA

$$\alpha = -arctan\frac{V_{B_z}}{V_{B_x}} \quad [2.40\text{-}27]$$

The negative sign is required because a negative V_{Bz} produces a positive α. Fin plane 1 is defined as being along the x-body axis in the x-y body plane. Therefore, the AOA for fin plane 1 is equal to the pitch angle of attack. In equation form:

$$\alpha 1 = \alpha \quad [2.40\text{-}28]$$

where α_1 = AOA of fin plane 1

Fin plane 2 is perpendicular to fin plane 1 in the x-z body plane. Its AOA is related to the velocity with respect to the wind in the y-direction. In a development similar to fin plane 1, fin plane 2 AOA is:

$$\alpha_2 = -arctan\frac{V_{B_y}}{V_{B_x}} \quad [2.40\text{-}29]$$

where $\alpha 2$ = AOA of fin plane 2

Design Element 40-5: Calculation of Aerodynamic Lift and Drag

The axis along which lift and drag forces act are aligned with the velocity vector and not the missile body axis. Consequently, lift and drag force each have three components resolved along the body axis system. A complete development of these force components is very complex but with a few assumptions can be simplified considerably.

Since the component of the velocity is much larger in the x-body direction compared to the y or z body directions it is not unreasonable to assume that the drag forces in the y and z body directions are negligible. Also, the contribution of lift in the x body direction is small but not in the y and z body directions. To restate then, the only contribution to aerodynamic forces in the x body direction are due to drag and the only contribution to aerodynamic forces in the y and z body directions is lift. This is how ESAMS simplifies the aerodynamic forces.

At this point we require a means of expressing the forces due to lift and drag as functions of known quantities. The equations for lift and drag are (Reference 25, page 24):

$$L = \frac{1}{2}\rho V_t^2 S C_L \qquad [2.40\text{-}30]$$

$$D = \frac{1}{2}\rho V_t^2 S C_D \qquad [2.40\text{-}31]$$

where
- ρ = air density
- V_t = total velocity
- S = reference area
- C_L = lift coefficient
- C_D = drag coefficient

From Equation [2.40-18], the term $\frac{1}{2}\rho V_t^2$ is known as the dynamic pressure, referred to as Q. C_L and C_D are constants of proportionality known as aerodynamic coefficients and, C_L and C_D, and all other aerodynamic coefficients, are dimensionless quantities used to represent the aerodynamic parameters of the missile. They vary depending on Mach number, angle of attack (AOA), surface deflections and missile body shape.

Total drag coefficient, C_D, is the sum of base drag, C_{Do}, and drag due to lift or induced drag, C_{Di}. Base drag is the drag the missile body generates with a zero angle of attack. It varies with Mach number and altitude (air density). ESAMS has values for C_{Di} for various Mach numbers and altitudes stored in look-up tables. Induced drag is drag caused by the lift being produced by the missile and is proportional to lift coefficient (Reference 25, page 186),

$$C_{D_i} = \alpha C_L \qquad [2.40\text{-}32]$$

C_{Di} varies with Mach number, AOA and control surface deflections. ESAMS has values for C_{Di} for various Mach numbers, AOAs and surface deflections stored in look-up tables. Therefore:

$$C_D = C_{D_0} + C_{D_i} \qquad [2.40\text{-}33]$$

From above, lift has components in the y and z body directions. Lift is generated by deflections of the control surfaces. By definition, y forces are perpendicular to the fins in the z plane, represented by C_{Ly} , and z forces are perpendicular to the fins in the y plane, represented by C_{Lz}. C_{Lz} and C_{Ly} vary with Mach number, AOA and surface deflection. ESAMS has values for C_{Lz} and C_{Ly} for various Mach numbers, AOAs and surface deflections stored in lookup tables.

Using the simplifications employed by ESAMS, the final set of equations that define the aerodynamic forces acting in the three body directions are:

$$F_x = D = QSC_D \qquad [2.40\text{-}34]$$

$$F_y = L_y = QSC_{L_y} \qquad [2.40\text{-}35]$$

$$F_z = L_z = QSC_{L_z} \qquad [2.40\text{-}36]$$

If there is a component of engine thrust in the y or z directions, it is simply added to the appropriate equation following proper sign conventions. This is true for some of the missiles modeled by ESAMS.

Design Element 40-6: Calculation of Aerodynamic Moments

The application of a moment about the CG generates angular accelerations defined by the Equations [2.40-13,14, and 15]. The two principal causes of moments are, the moment caused by uneven distribution of forces represented by the coefficient C_M , and moments caused by lift acting some distance from the CG. The equation for a moment caused by the uneven distribution of forces is (Reference 25, page 150)

$$M_B = QS\bar{c}C_M \qquad [2.40\text{-}37]$$

where M_B = body moment
$\bar{c}$ = mean aerodynamic chord
C_M = moment coefficient

The mean aerodynamic chord, $\bar{c}$, is defined as the reference length that, when multiplied by the reference area, the dynamic pressure and C_M , gives the total moment about the aerodynamic center. In other words, it is chosen to give a moment which agrees with the observed value.

As with lift, moment has a component about the y axis known as pitching moment and a component about the z axis known as yawing moment defined by the coefficients C_{My} and C_{Mz}. C_{My} and C_{Mz} vary with Mach number, AOA, and control surface deflections. ESAMS has coefficient values for various Mach numbers, AOAs and control surface deflections stored in look-up tables.

Lift also causes a moment about the CG because it acts through the center of pressure. The contribution of lift force to moment about the y and z axes are:

$$\text{y}-\text{axis,}\quad M_L = QSC_{L_y}(CG - CP);\ \text{pitch} \qquad [2.40\text{-}38]$$

$$\text{z}-\text{axis},\;\; N_L = QSC_{L_z}(CG - CP);\;\; \text{y}aw \qquad [2.40\text{-}39]$$

where (CG-CP) = distance from center of gravity and center of pressure, or moment arm
The values for C_{Lz} and C_{Ly} are identical to those obtained from the calculation of lift.

Combining equations for common axes gives:

$$M = M_B + M_L = QS\left(\bar{c}C_{M_y} + C_{L_y}(CG - CP)\right) \qquad [2.40\text{-}40]$$

$$N = M_B + N_L = QS\left(\bar{c}C_{M_z} + C_{L_z}(CG - CP)\right) \qquad [2.40\text{-}41]$$

If there is a component of thrust in the y or z directions, its contribution to the moment about the y or z axis is added to the appropriate equation after being multiplied by length from the engine nozzle to the center of gravity. This is true for some of the missiles modeled by ESAMS.

Figure 2.40-6 illustrates forces and moment arms contributing to moments about the y-axis. The forces and moment arms about the z axis are similar.

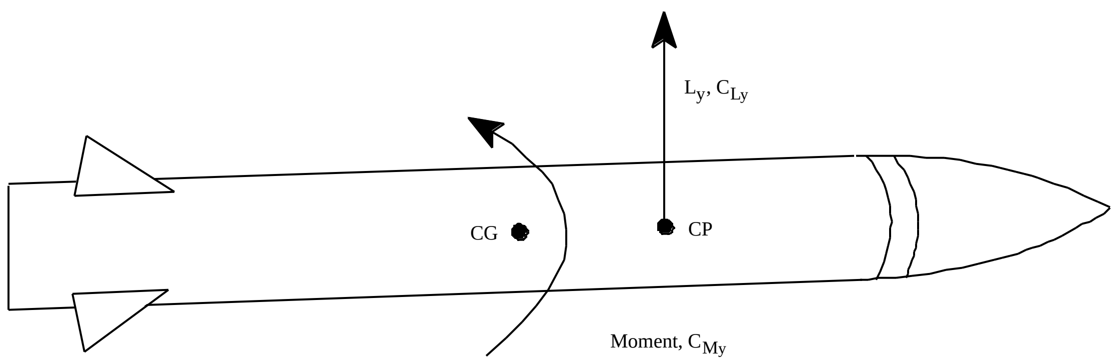

FIGURE 2.40-6. Forces and Moments Around the Y-Axis.

Design Element 40-7: Heading and Flight Path Angles

To determine in which direction the missile is flying in inertial space, the heading and flight path angles are computed using simple vector relations. Missile heading, ψ_V, is the angle between the velocity in the inertial x-direction, V_{Ix}, and the velocity in the inertial y-direction, V_{Iy}. Figure 2.40-7 illustrates these velocity vectors.

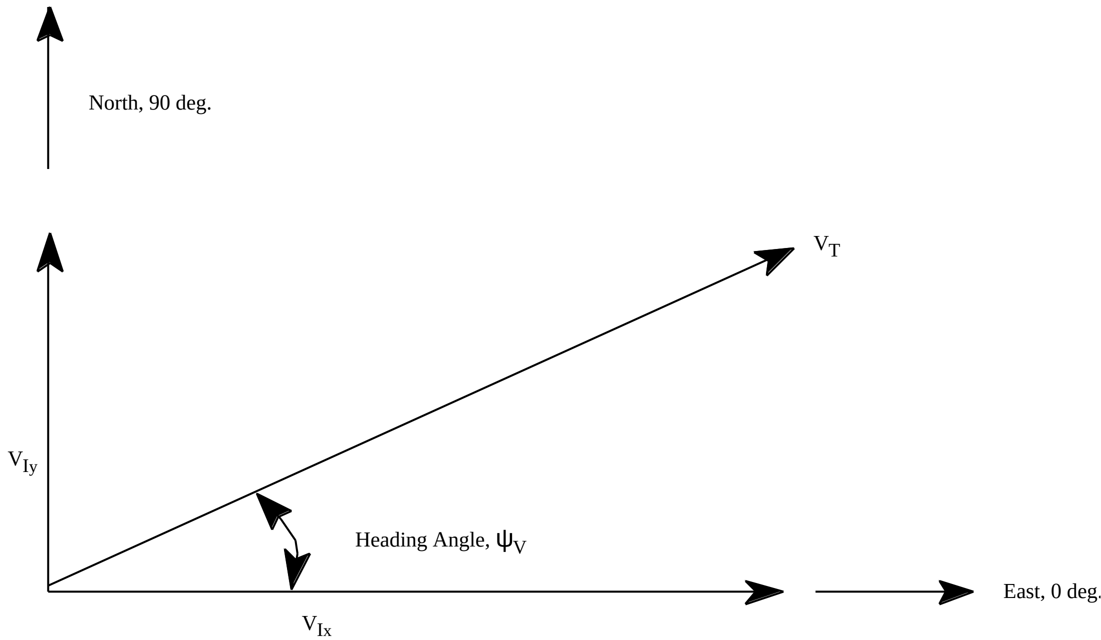

FIGURE 2.40-7. Velocity Vectors.

Therefore:

$$\psi_V = \arctan\left(\frac{V_{I_y}}{V_{I_x}}\right) \quad [2.40\text{-}42]$$

Flight path angle, γ, is the angle from the horizontal along which total velocity is directed. It is determined from the vector relationship between total velocity and the inertial velocity in the z-direction, V_{Iz}. Refer to Figure 2.40-2 for an illustration of flight path angle. Therefore:

$$\gamma = \arcsin\left(\frac{V_{I_z}}{V_t}\right) \quad [2.40\text{-}43]$$

Design Element 40-8: Calculation of Pitch and Yaw Body Rates

The orientation of the missile fin planes is either in the pitch and yaw planes as in Figure 2.40-8a or canted 45 degrees as in Figure 2.40.8b. If they are in the pitch and yaw planes, by definition the pitch and yaw rates are equal to the body rates around the y and z axes respectively. If they are canted at 45 degrees, then each of the body rates, which are aligned with the y and z body axes, contribute to pitch and yaw rates. In equation form the vectors combine as follows:

$$\text{Pitch rate}: \quad \dot{\theta} = q\cos 45^\circ + r\cos 45^\circ \quad [2.40\text{-}44]$$

$$\text{Yaw rate}: \quad \dot{\psi} = q\sin 45^\circ + r\cos 45^\circ \quad [2.40\text{-}45]$$

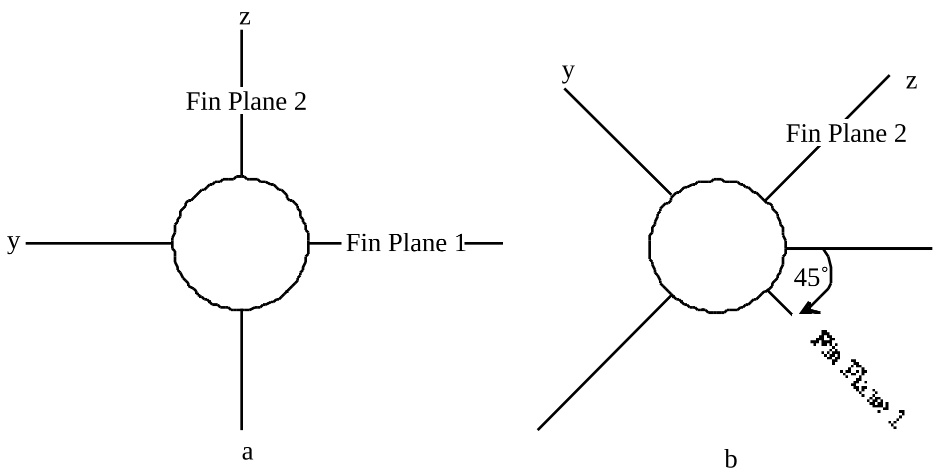

FIGURE 2.40-8. Orientation of Fin Planes.

2.40.3 Functional Element Software Design

This section contains the software design necessary to implement the functional element requirements described in Section 2.40.1 and the design approach described in Section 2.40.2. Section 2.40.3 is organized as follows: the first section describes the subroutine hierarchy and gives descriptions of the relevant subroutines; the next subsection contains logical flow charts and describes all important operations represented by each block in the charts; the last subsection contains a description of all input and output data for the functional element as a whole and for each subroutine that implements force and moment generation.

Force and Moment Generation Subroutine Design

The FORTRAN call tree implemented for the Force and Moment Generation Functional Element in ESAMS code is shown in Figure 2.40-9. The diagram depicts the structure of the entire model for this functional element, from ZINGER (the main program) through the least significant subroutine implementing force and moment generation. Subroutines which directly implement the functional element appear as shaded blocks. Each of these subroutines is described briefly in Table 2.40.2.

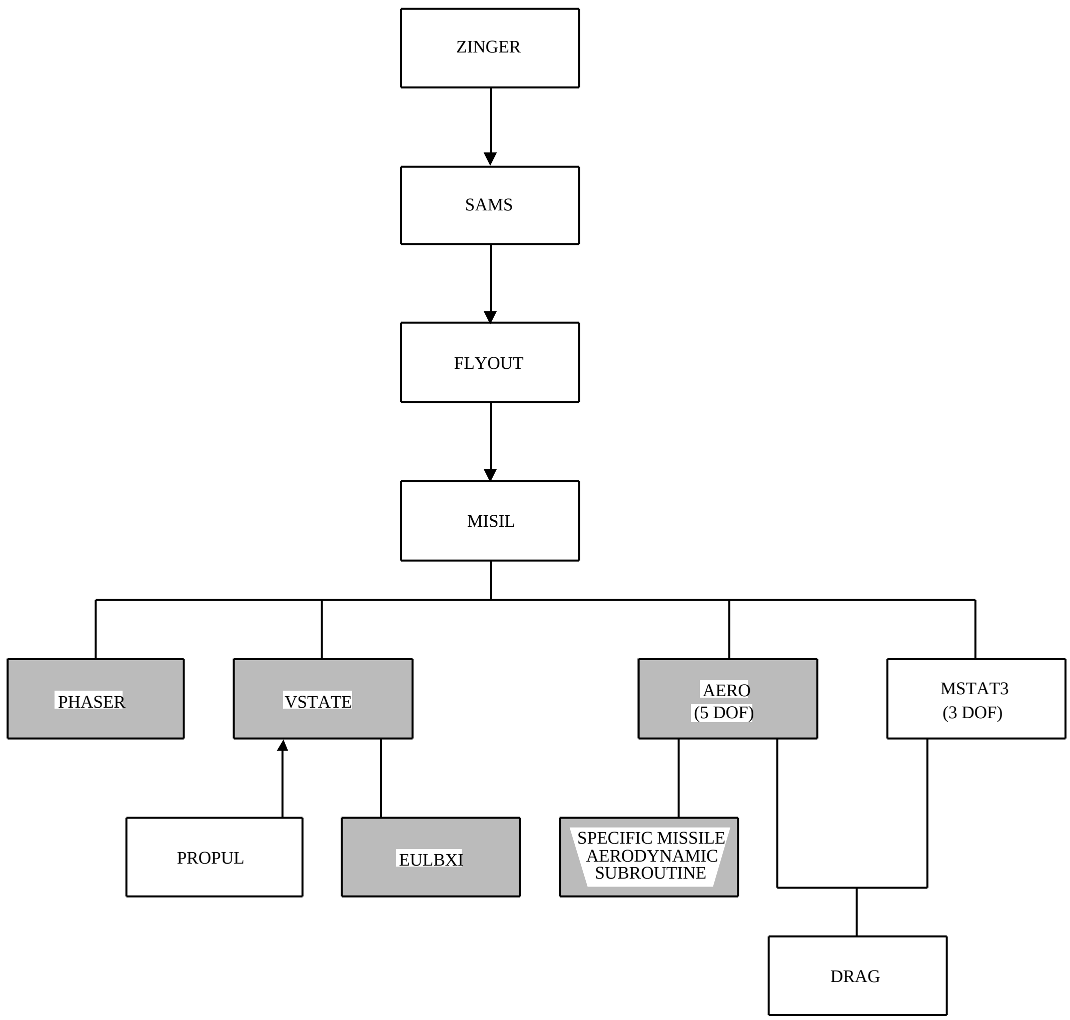

FIGURE 2.40-9. Call Hierarchy for Force and Moment Generation.

TABLE 2.40-2. Subroutine Descriptions.

Module Name	Description
PHASER	Determines whether the current stage will end based on time or mass, sets ISTAGE counter.
VSTATE	Computes parameters required for force and moment calculations, flight path angles and rates.
EULBXI	Calculates direction cosine matrix for body to inertial transformation using either primary or secondary Euler angles.
AERO	Calls specific subroutine to calculate aerodynamic coefficients, computes body force and torque vectors.
(SPS)*	Computes specific lift, drag and moment coefficients based on look-up tables.
MSTAT3	Calculate forces and moments for 3-DOF model.
DRAG	Generalized subroutine which calculates drag coefficients if system is not specifically called out under specific Missile Subroutine.

Note: Modules implementing the force and moment calibration functional element are identified in bold letters.
* Specific Missile Subroutine. Numerous subroutines exist, one for each missile system modeled

Functional Flow Diagram

Figure 2.40.10 shows the top-level logical flow of the force and moment generation implementation. Subroutine names appear in the parentheses at the bottom of each process block. The numbered blocks are described below.

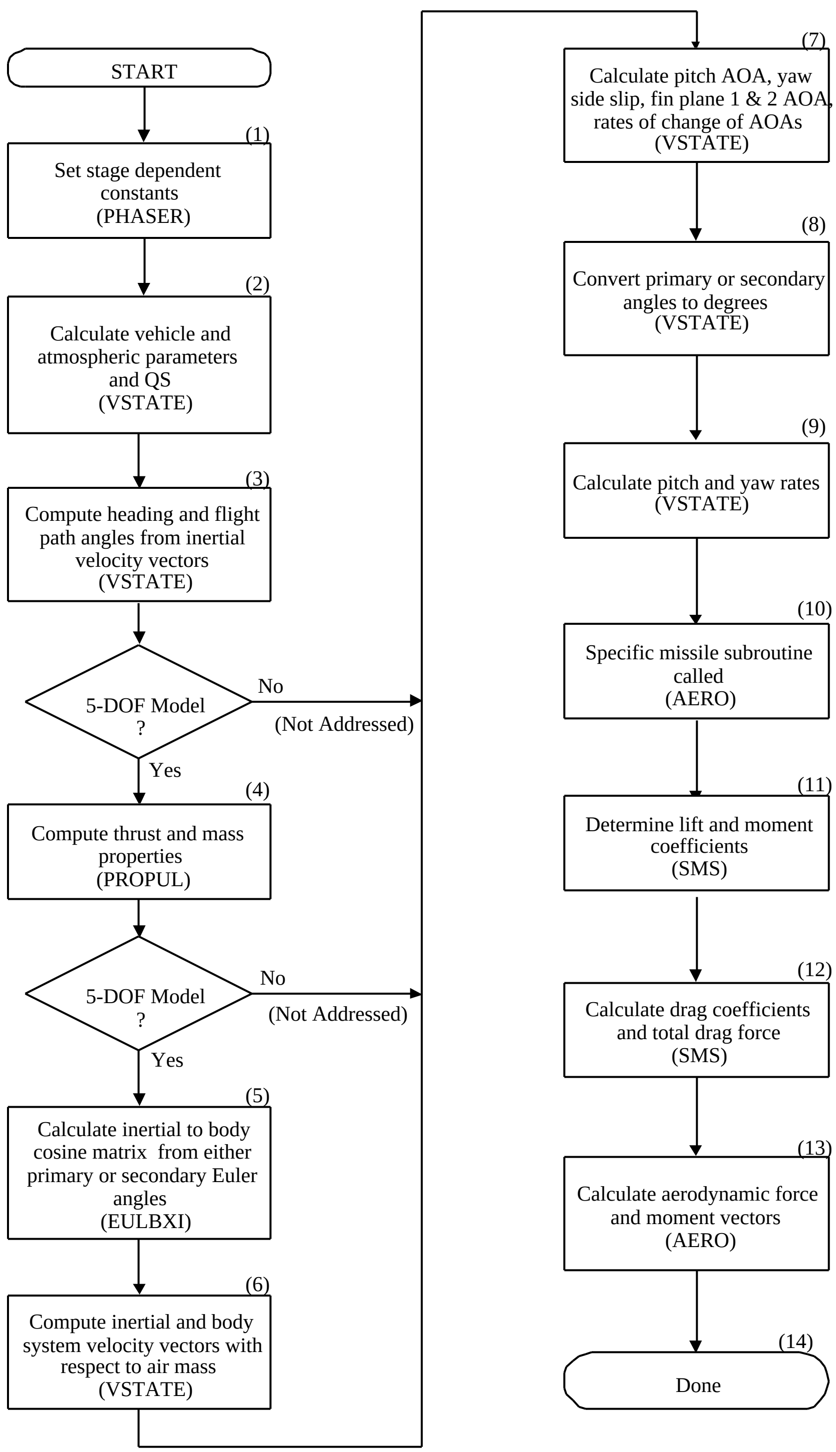

FIGURE 2.40-10. Force and Moment Generation Logical Flow.

Block 1. Subroutine PHASER checks the phase ending code to determine whether the current missile stage will end based on time or on mass. The appropriate parameter is checked to determine whether or not staging is to occur during the current autopilot integration step. If so, the following operations are done: time to end the following stage is set; engine exit area (from look-up table); table pointers and drag table indices are initialized; and for each stage change, PRNTM is called to print missile and target data.

Block 2. The appropriate altitude needed for determination of atmospheric conditions is computed. Subroutine ATMOS is called to provide atmospheric density (r), temperature (ATEMP), pressure (APRESS), and speed of sound (VSONIC). Total velocity is computed from the three inertial velocity components using Equation [2.40-16]. Compute Mach number using Equation [2.40-17] and dynamic pressure, Q using Equation [2.40-18]. Since they are always used together, dynamic pressure and reference area, S, are multiplied to provide the quantity, QS.

Block 3. Compute heading (PSIM) and flight path angle (GAMMA) from inertial velocity vectors using Equations [2.40-42 and 43].

Block 4. Subroutine PROPUL provides thrust, mass, moments of inertia, center of gravity location and center of pressure location.

Block 5. Subroutine EULBXI is called to calculate inertial to body direction cosine matrix based on Equations [2.40-23 or 24].

Block 6. Wind speed and direction is provided by WINDS look-up table. Missile inertial velocities with respect to air mass in 3 component directions are calculated using Equation [2.40-25]. Body system velocities with respect to air mass are computed using the direction cosine matrix, Equation [2.40-26].

Block 7. Using body system velocities with respect to air mass, calculate pitch AOA using Equation [2.40-27], yaw side slip angle, AOA of fin plane 1 using Equation [2.40-28] and AOA of fin plane 2 using Equation [2.40-29]. Approximate angle of attack rates in both fin planes are calculated from body angular rates and body angular accelerations.

Block 8. If secondary Euler angles are being used, (IULR=1) then subroutine BXIEUL calculates primary Euler angles. These angles are converted to degrees and the real Euler angles are restored before returning to program. If primary Euler angles are being used, they are converted to degrees without updating.

Block 9. Body rates for pitch and yaw (OMEG(2), OMEG(3)) are used to calculate body pitch and yaw rates (PRATE, YRATE). This calculation is dependent on missile orientation (IXCRD) as in Equation [2.40-44 and 45].

Block 10. Subroutine AERO calls the specific missile subroutine being modeled.

Block 11. Using current Mach number, AOA and control surface deflection data, lift (C_L) and moment (C_M) coefficients for the 2 fin planes are determined from lookup tables for the specific missile system being modeled.

Block 12. Using current Mach number and altitude the basic drag coefficient, C_{Do}, is determined from a look-up table for the specific missile system being modeled. Incremental or induced drag coefficient, C_{Di}, is also determined from a look-up table based additionally on control surface deflections. Using Equation [2.40-33], total drag coefficient, C_D, is calculated. Total drag force, FD, is then computed from Equation [2.40-34]. (THNFC1 and THNFC2 are zero for SMS under consideration.)

Block 13. Lift coefficients, C_{Lz} and C_{Ly}, generated in block 12 are used in Equations [2.40-35 and 36] to calculate aerodynamic forces in the z and y body directions. Lift and moment coefficients, C_{Lz}, C_{Ly}, C_{Mz}, C_{My} generated in block 12 are used in Equations [2.40-40 and 41] to calculate moments (or torques) around the y and z body axes.

Block 14. Values for forces and moments are now available to calculate body and inertial accelerations accomplished in subroutine ACCEL.

Force and Moment Generation Inputs and Outputs

The outputs of this functional element are angles, forces and moments given in Table 2.40-3. User inputs which affect force and moment generation are given in Table 2.40-4.

TABLE 2.40-3. Force and Moment Generation Outputs.

Variable Name	Description
PSIM	Missile inertial heading angle of velocity vector (rad)
GAMMA	Missile inertial flight path angle (rad)
PSIM2	Missile inertial heading of x-body axis
GAMMA2	Missile inertial pitch angle
PSIDG	Missile yaw angle (deg)
THETDG	Missile pitch angle (deg)
PHIDG	Missile roll angle (deg)
PRATE	Missile pitch body rate (rad/sec)
YRATE	Missile yaw body rate (rad/sec)
RHOX	Term from direction cosine transformation matrix relating missile body x-direction to inertial x-direction
RHOY	Term from direction cosine transformation matrix relating missile body x-direction to inertial y-direction
RHOZ	Term from direction cosine transformation matrix relating missile body x-direction to inertial z-direction
PIX	Term from direction cosine transformation matrix relating missile body y-direction to inertial x-direction
PIY	Term from direction cosine transformation matrix relating missile body y-direction to inertial y-direction
PIZ	Term from direction cosine transformation matrix relating missile body y-direction to inertial z-direction
ETAX	Term from direction cosine transformation matrix relating missile body z-direction to inertial x-direction
ETAY	Term from direction cosine transformation matrix relating missile body z-direction to inertial y-direction
ETAZ	Term from direction cosine transformation matrix relating missile body z-direction to inertial z-direction
FA(1)	Force in x-body direction (kg)
FA(2)	Force in y-body direction (kg)
FA(3)	Force in z-body direction (kg)
TAUA(1)	Moment around x-body axis, roll (kgm)
TAUA(2)	Moment around y-body axis, pitch (kgm)
TAUA(3)	Moment around z-body axis, yaw (kgm)

TABLE 2.40-4. User Inputs for Force and Moment Generation.

Common Name	Variable Name	Description
MSLD	PCDI	Table pointer for incremental drag coefficient
MSLD	PCL1	Table pointer for CL1 lift coefficient
MSLD	PCL2	Table pointer for CL2 lift coefficient
MSLD	PCM1	Table pointer for CM1 moment coefficient
MSLD	PCM2	Table pointer for CM2 moment coefficient
MSLD	FLGMSL (array)	Missile simulation flags
MSLD	FLGMSL (7) IXCRD	Fin plane orientation flag
MSLD	FLGMSL (10) IAERO	Specific missile aerodynamic subroutine selection flag
MSLD	FLGMSL (16) IDOF	Degree of freedom in simulation
MSLD	FLGMSL (19) IAUTO	Autopilot update rate
MSLD	AREF	Missile reference area
MSLD	BODYL	Missile body length
MSLD	GFACT	Guidance factor
MSLD	REFL	Missile reference length
MSLD	PHENDC	Missile phase end codes for each phase
MSLD	PHMASS	Mass at beginning of phase
MSLD	SC	Simulation constants
MSLD	TALPHA	Limit on angle of attack for coefficient look-up
MSLD	TAREA	Table area for lookup tables
MSLD	TCD	Staging times
MSLD	PCD	Table pointer for basic drag coefficient
PROGC	ALTXYZ	Altitude correction factor (m)
PROGC	WINDAB	Wind azimuth bias
PROGC	WINDAC	Wind altitude units conversion factor
PROGC	WINDVC	Wind velocity units conversion factor

Inputs and outputs for the major routines implementing force and moment generation functional element are given in Table 2.40-5 through 2.40-9. Several of the subroutines perform functions unrelated to our specific missile system. Thus, the inputs and outputs related to our missile of interest are printed in bold.

TABLE 2.40-5. Subroutine PHASER Inputs and Outputs.

SUBROUTINE: PHASER					
Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
KAST	Common SIMVI	Missile integration step counter	TSTAGE	Common MISSIL	Missile staging time
ISTAGE	Common SIMVI	Current missile stage	AEXIT	Common MISSIL	Exit area for current stage
PHENDC	Common MSLD	Missile phase-end codes for each phase (stage)	JCDX	Common SIMVI	Current basic drag coefficient pointer
ATIME	Common GUIDAP	Autopilot time	JCDIX	Common SIMVI	Current incremental drag coefficient pointer
XDT	Argument	Autopilot step time for 5 DOF simulations	JALPMX	Common SIMVI	Current JALMX1 pointer
EPSILN	Common PARAM	A small number	LCD1	Common TLUPT	Table index for basic drag coefficient (first dimension)
FMASS	Common MISSIL	Mass of missile	LCD2	Common TLUPT	Table index for basic drag coefficient (second dimension)
PHMASS	Common MSLD	Mass at beginning of phase (stage)	LCDI1	Common TLUPT	Table index for incremental drag coefficient (first dimension)
TCD	Common MSLD	Staging times	LCDI2	Common TLUPT	Table index for incremental drag coefficients (second dimension)
EXITA	Common MSLD	Exit area for each stage	LCDI3	Common TLUPT	Table index for incremental drag coefficient (third dimension)
JCD	Common RUNVI	Array of pointers for basic drag coefficients	IPEVNT	Common SIMVI	Flyout event print flag
JCDI	Common RUNVI	Array of table pointers for incremental drag coefficients	IPSTG	Common SIMVI	Staging change flag
JALMX1	Common RUNVI	Array of table pointers for maximum angle of attack			

TABLE 2.40-6. Subroutine VSTATE Inputs and Outputs.

SUBROUTINE: VSTATE					
Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
Z	Common MISSIL	Missile Z coordinate in ICS	ALT	Common ENVRN	Missile mean-sea-level altitude for Call to ATMOS (m)
ALTXYZ	Common PROGC	Altitude correction factor	V2	Common MISSIL	Missile velocity squared (m2/sec2)
XDOT	Common MISSIL	Missile velocity in inertial X direction	V	Common MISSIL	Missile velocity magnitude (m/sec))
YDOT	Common MISSIL	Missile velocity in inertial Y direction	FMACH	Common MISSIL	Missile mach numbers
ZDOT	Common MISSIL	Missile velocity in inertial Z direction	Q	Common MISSIL	Dynamic pressure (kg/sec2m)

TABLE 2.40-6. Subroutine VSTATE Inputs and Outputs. (Contd.)

SUBROUTINE: VSTATE

Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
IAERO	Common ROPTN	Aero routine selection, based on specific missile	QS	Common MISSIL	Dynamic pressure times reference area (N)
AREF	Common MSLD	Reference area	PSIM	Common MISSIL	Missile yaw angle (heading) of velocity vector (rad)
IAUTO	Common ROPTN	Number of times to go through autopilot - zero	GAMMA	Common MISSIL	Missile pitch angle of velocity vector (rad)
IWIND	Common ROPTN	Wind option	SW	Common ENVRN	Wind speed (m/sec)
WINDAC	Common PROGC	Wind altitude units conversion factor	AZW	Common ENVRN	Wind azimuth, direction wind is from (rad)
WINDS	Common WIND	Wind profile; altitude, velocity, direction	VWX	Common MISSIL	Missile inertial X velocity component in wind axis system (m/sec)
WINDVC	Common PROGC	Wind velocity units conversion factor	VWY	Common MISSIL	Missile inertial Y velocity component in wind axis system (m/sec)
WINDAB	Common PROGC	Wind azimuth bias	VWZ	Common MISSIL	Missile inertial Z velocity component in wind axis system (m/sec)
DTR	Common PARAM	Degrees to radians conversion factor	VRBX	Common MISSIL	Missile velocity in x-body direction relative to the wind (m/sec)
RHOX	Common EULER	Term from direction cosine transformation matrix relating missile body x-direction to inertial x-direction	VRBY	Common MISSIL	Missile velocity in y-body direction relative to the wind (m/sec)
RHOY	Common EULER	Term from direction cosine transformation matrix relating missile body x-direction to inertial y-direction	VRBZ	Common MISSIL	Missile velocity in z-body direction relative to the wind (m/sec)
RHOZ	Common EULER	Term from direction cosine transformation matrix relating missile body x-direction to inertial z-direction	ALFA	Common MISSIL	Pitch angle of attack (rad)
PIX	Common EULER	Term from direction cosine transformation matrix relating missile body y-direction to inertial x-direction	BETA	Common MISSIL	Side slip angle of attack (rad)
PIY	Common EULER	Term from direction cosine transformation matrix relating missile body y-direction to inertial y-direction	ALPHA1	Common MISSIL	Angle of attack of fin plane 1 (rad)
PIZ	Common EULER	Term from direction cosine transformation matrix relating missile body y-direction to inertial z-direction	ALPHA2	Common MISSIL	Angle of attack of fin plane 2 (rad)

TABLE 2.40-6. Subroutine VSTATE Inputs and Outputs. (Contd.)

SUBROUTINE: VSTATE

Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
ETAX	Common EULER	Term from direction cosine transformation matrix relating missile body z-direction to inertial x-direction	ALPHAT	Common MISSIL	Total angle of attack (rad)
ETAY	Common EULER	Term from direction cosine transformation matrix relating missile body z-direction to inertial y-direction	ALFDT1	Common MISSIL	Rate of change of ALPHA1 (rad/sec)
ETAZ	Common EULER	Term from direction cosine transformation matrix relating missile body z-direction to inertial z-direction	ALFDT2	Common MISSIL	Rate of change of ALPHA2 (rad/sec)
LWINDS	Common TLUPT	Table index for wind data	PSIDG	Common EULER	Missile yaw angle, heading (deg)
R2D	Common PARAM	Radians to degrees conversion factor	PHIDG	Common EULER	Missile roll angle (deg)
OMEG(2)	Common MISSIL	Missile body angular rate around y-axis	THETDG	Common EULER	Missile pitch angle (deg)
OMEG(3)	Common MISSIL	Missile body angular rate around z-axis	PRATE	Common GUIDAP	Pitch body rate (rad/sec)
ZDDB	Common MISSIL	Missile body acceleration in z direction	YRATE	Common GUIDAP	Yaw body rate (rad/sec)
XDDB	Common MISSIL	Missile body acceleration in x direction	RHO	Common ENVRN	Air density at missile mean-sea-level altitude (k8/m3)
YDDB	Common MISSIL	Missile body acceleration in y direction	ATEMP	Common ENVRN	Air temperature at missile mean-sea-level altitude (deg C)
LPFLG	Common SIMVI	Last pass flag for VSTATE	APRESS	Common ENVRN	Air pressure at missile mean-sea-level altitude (N/m2)
IULR	Common SIMVI	Primary or secondary Euler angle selection	VSONIC	Common ENVRN	Speed of sound at missile mean-sea-level altitude (m/sec)
PSI	Common EULER	Missile yaw angle	PSIM2	Common MISSIL	Pointing angle of missile body in pitch
PHI	Common EULER	Missile roll angle	GAMMA2	Common MISSIL	Heading angle of missile body
THET	Common EULER	Missile pitch angle			
IXCRD	Common ROPTN	Missile axis configuration selection			
SR202	Common PARAM	Square root of 2 divided by 2			

TABLE 2.40-7. Subroutine EULBXI Inputs and Outputs.

SUBROUTINE: EULBXI					
Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
THET	Common EULER	Missile inertial pitch angle (rad)	RHOX	Common EULER	Term from direction cosine transformation matrix relating missile body x-direction to inertial x-direction
PSI	Common EULER	Missile inertial yaw angle (rad)	RHOY	Common EULER	Term from direction cosine transformation matrix relating missile body x-direction to inertial y-direction
PHI	Common EULER	Missile inertial roll angle (rad)	RHOZ	Common EULER	Term from direction cosine transformation matrix relating missile body x-direction to inertial z-direction
IULR	Common SIMVI	Flag indicating primary or secondary Euler angles are being used	PIX	Common EULER	Term from direction cosine transformation matrix relating missile body y-direction to inertial x-direction
			PIY	Common EULER	Term from direction cosine transformation matrix relating missile body y-direction to inertial y-direction
			PIZ	Common EULER	Term from direction cosine transformation matrix relating missile body y-direction to inertial z-direction
			ETAX	Common EULER	Term from direction cosine transformation matrix relating missile body z-direction to inertial x-direction
			ETAY	Common EULER	Term from direction cosine transformation matrix relating missile body z-direction to inertial y-direction
			ETAZ	Common EULER	Term from direction cosine transformation matrix relating missile body z-direction to inertial z-direction
			CTHT	Common EULER	Cosine of THET
			STHT	Common EULER	Sine of THET
			CPSI	Common EULER	Cosine of PSI
			SPSI	Common EULER	Sine of PSI
			CPHI	Common EULER	Cosine of PHI
			SPHI	Common EULER	Sine of PHI

TABLE 2.40-8. Subroutine AERO Inputs and Outputs.

SUBROUTINE: AERO

Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
IAERO	Common ROPTN	Flag used to determine which missile specific aero subroutine is to be called	FA(1)	Common MISSIL	Body force vector component in x-direction (N)
FD	Common MISSIL	Force due to drag (N)	FA(2)	Common MISSIL	Body force vector component in y-direction (N)
CL1	Common MISSIL	Coefficient of lift in fin plane 1	FA(3)	Common MISSIL	Body force vector component in z-direction (N)
CL2	Common MISSIL	Coefficient of lift in fin plane 2	TAUA(1)	Common MISSIL	Body aerodynamic torque vector around x-axis (roll moment (Nm)
QS	Common MISSIL	Dynamic pressure times reference area (N)	TAUA(2)	Common MISSIL	Body aerodynamic torque vector around y-axis (pitch moment (Nm)
GFACT	Common MSLD	Guidance factor - constant based on specific missile	TAUA(3)	Common MISSIL	Body aerodynamic torque vector around z-axis (yaw moment) (Nm)
THNFC1	Common MISSIL	Component of thrust vectoring (if any) in fin plane 1 (N)			
THNFC2	Common MISSIL	Component of thrust vectoring (if any) in fin plane 2 (N)			
REFL	Common MSLD	Missile reference length - based on physical characteristics of specific missile (m)			
CM1	Common MISSIL	Moment coefficient in fin plane 1			
CM2	Common MISSIL	Moment coefficient in fin plane 2			
CG	Common MISSIL	Missile center of gravity offset along x-body axis (m)			
CP	Common MISSIL	Location of missile center of pressure (m)			
BODYL	Common MSLD	Missile body length (m)			

TABLE 2.40-9. Subroutine AERO8 Inputs and Outputs.

SUBROUTINE: AERO8

Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
SC	Common MSLD	Simulation constants	CM1	Common MISSIL	Moment coefficient in fin plane 1
FMACH	Common MISSIL	Missile Mach number	CM2	Common MISSIL	Moment coefficient in fin plane 2
ALPHA1	Common MISSIL	Angle of attack of fin plane 1 (rad)	CL1	Common MISSIL	Coefficient of lift in fin plane 1
ALPHA2	Common MISSIL	Angle of attack of fin plane 2 (rad)	CL2	Common MISSIL	Coefficient of lift in fin plane 2
CON1	Common GUIDAP	Deflection angle of fin plane 1	FD	Common MISSIL	Force due to drag (N)
CON2	Common GUIDAP	Deflection angle of fin plane 2			
R2D	Common CONST	Radians to degrees conversion factor			
TALPHA	Common MSLD	Limit on angle of attack for aerodynamic calculations, used to keep ALPHA1 within look-up table limits			
TAREA	Common MSLD	Defines table area for look-up tables			
LCM1* *=1,2 or 3	Common TLUPT	Table index for CM1 moment coefficient look-up table (first, second or third dimension)			
LCM2* *=1,2 or 3	Common TLUPT	Table index for CM2 moment coefficient look-up table (first, second or third dimension)			
LCL1* *=1,2 or 3	Common TLUPT	Table index for CL1 lift coefficient look-up table (first, second or third dimension)			
LCL2* *=1,2 or 3	Common TLUPT	Table index for CL2 lift coefficient look-up table (first, second or third dimension)			
LBCM1* *=1,2 or 3	Common TLUPT	Table index for CM10 moment coefficient look-up table for 0 surface deflection (first, second or third dimension)			
LBCM2* *=1,2 or 3	Common TLUPT	Table index for CM20 moment coefficient look-up table for 0 surface deflection (first, second or third dimension)			
LBCL1* *=1,2 or 3	Common TLUPT	Table index for CM10 lift coefficient look-up table for 0 surface deflection (first, second or third dimension)			

TABLE 2.40-9. Subroutine AERO8 Inputs and Outputs. (Contd.)

SUBROUTINE: AERO8

Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
LBCL2* *=1,2 or 3	Common TLUPT	Table index for CM20 lift coefficient look-up table for 0 surface deflection (first, second or third dimension)			
JCM1	Common RUNVI	Table pointer for CM1 and CM10 moment coefficient look-up table			
JCM2	Common RUNVI	Table pointer for CM2 and CM20 moment coefficient look-up table			
JCL1	Common RUNVI	Table pointer for CL1 and CL10 lift coefficient look-up table			
JCL2	Common RUNVI	Table pointer for CL2 and CL20 lift coefficient look-up table			
ALT	Common ENVRN	Missile mean-sea-level altitude			
LCD1	Common TLUPT	Table index for basic drag coefficient look-up table (first dimension)			
LCD2	Common TLUPT	Table index for basic drag coefficient look-up table (second dimension)			
IRJCD	Common ROPTN	Ram jet drag coefficient selection			
ISTAGE	Common SIMVI	Current missile stage			
CRJ	Common MSLD	Ram jet sustainer coefficients			
APRESS	Common ENVRN	Air pressure at missile mean-sea-level altitude			
QS	Common MISSIL	Dynamic pressure times reference area (N)			
Z	Common MISSIL	Missile Z coordinate in inertial coordinate system (m)			
LCDI1	Common TLUPT	Table index for CDI1 incremental drag coefficient look-up table (first dimension)			
LCDI2	Common TLUPT	Table index for CDI1 incremental drag coefficient look-up table (second dimension)			

TABLE 2.40-10. Subroutine AERO8 Inputs and Outputs. (Contd.)

SUBROUTINE: AERO8					
Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
LCDI21	Common TLUPT	Table index for CDI2 incremental drag coefficient look-up table (first dimension)			
LCDI22	Common TLUPT	Table index for CDI2 incremental drag coefficient look-up table (second dimension)			
XMACH	Common MISSIL	Mach number LIMIT used in table look-ups			
JCDX	Common SIMVI	Table pointer for current basic drag coefficient look-up table			
JCDIX	Common SIMVI	Table pointer for incremental drag coefficient look-up table			

2.40.4 Assumptions and Limitations

The contribution of drag to forces in the y and z body directions is neglected as is the contribution of lift in the x direction.

The missile is assumed to be perfectly roll stabilized, that is, rolling moment is held to 0.

The lookup tables for lift, drag, and moment coefficients are limited by mach number and angle of attack.

The missile is assumed to have identical symmetry about the y and z body axes.

The atmospheric conditions in which the missile is flying is limited to standard day conditions.